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(54) **CATHETERS WITH INDEPENDENT RADIAL-EXPANSION MEMBERS AND ASSOCIATED DEVICES, SYSTEMS, AND METHODS**

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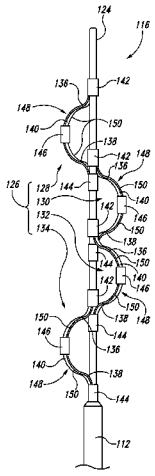
(57) **ABSTRACT**

A neuromodulation catheter includes an elongate shaft and a neuromodulation element operably connected to the shaft. The neuromodulation element includes an elongate support member and a plurality of bow springs operably connected to the support member. The individual bow springs are configured to independently expand radially outward from the support member when the neuromodulation element transitions from a low-profile delivery state to a deployed state at a treatment location within a body lumen. The individual bow springs include a distal leg and a proximal leg and carry an electrode and/or a transducer between their respective distal and proximal legs. The distal and proximal legs of the plurality of bow springs are longitudinally interdigitated. The plurality of bow springs is configured to urge the electrodes and/or the transducers into contact with an inner surface of a wall of the body lumen at a series of contact regions.

24 Claims, 10 Drawing Sheets



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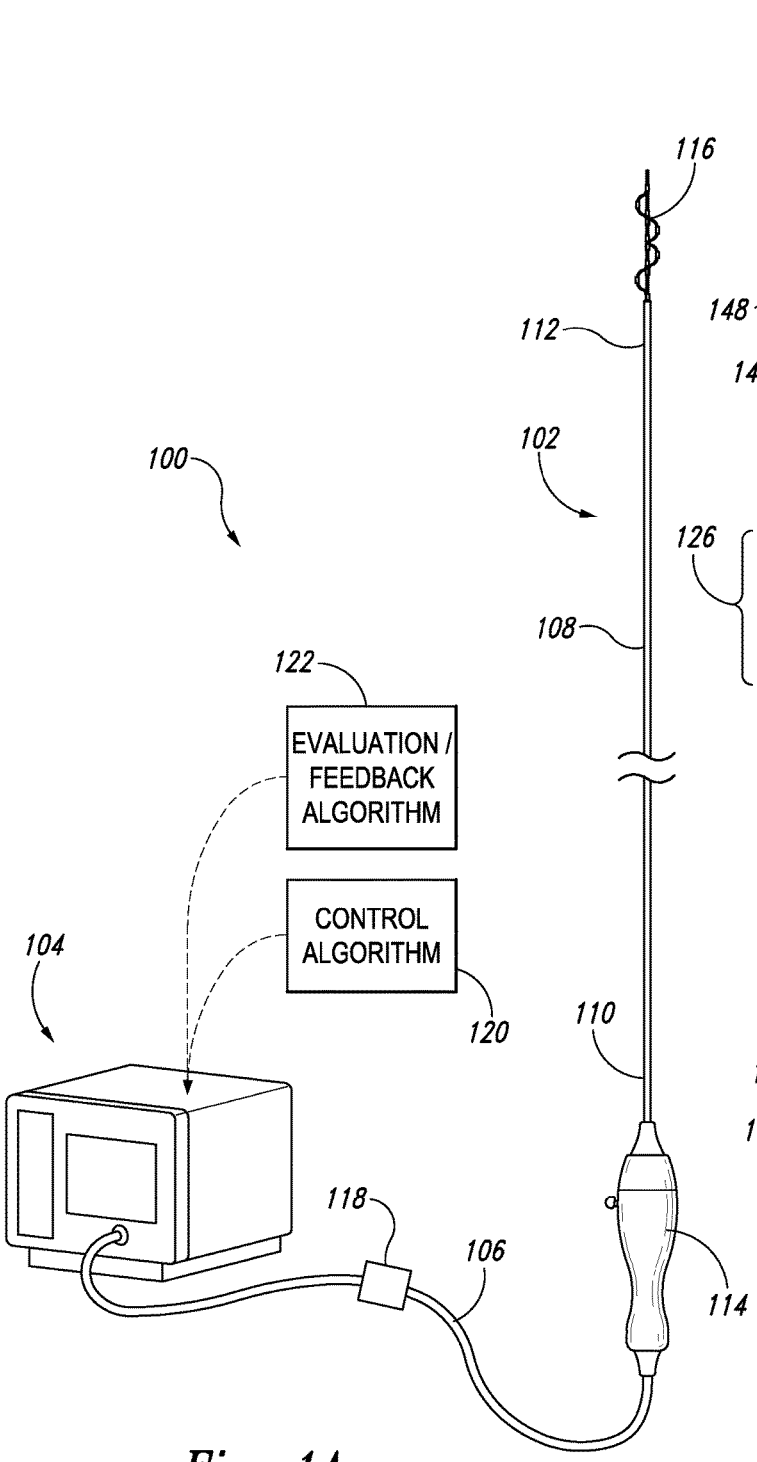
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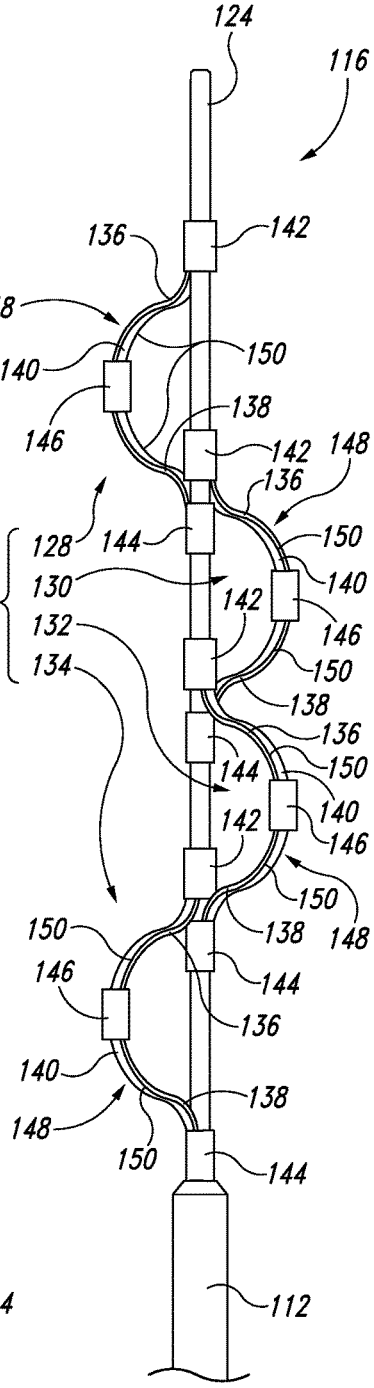
Fig. 1A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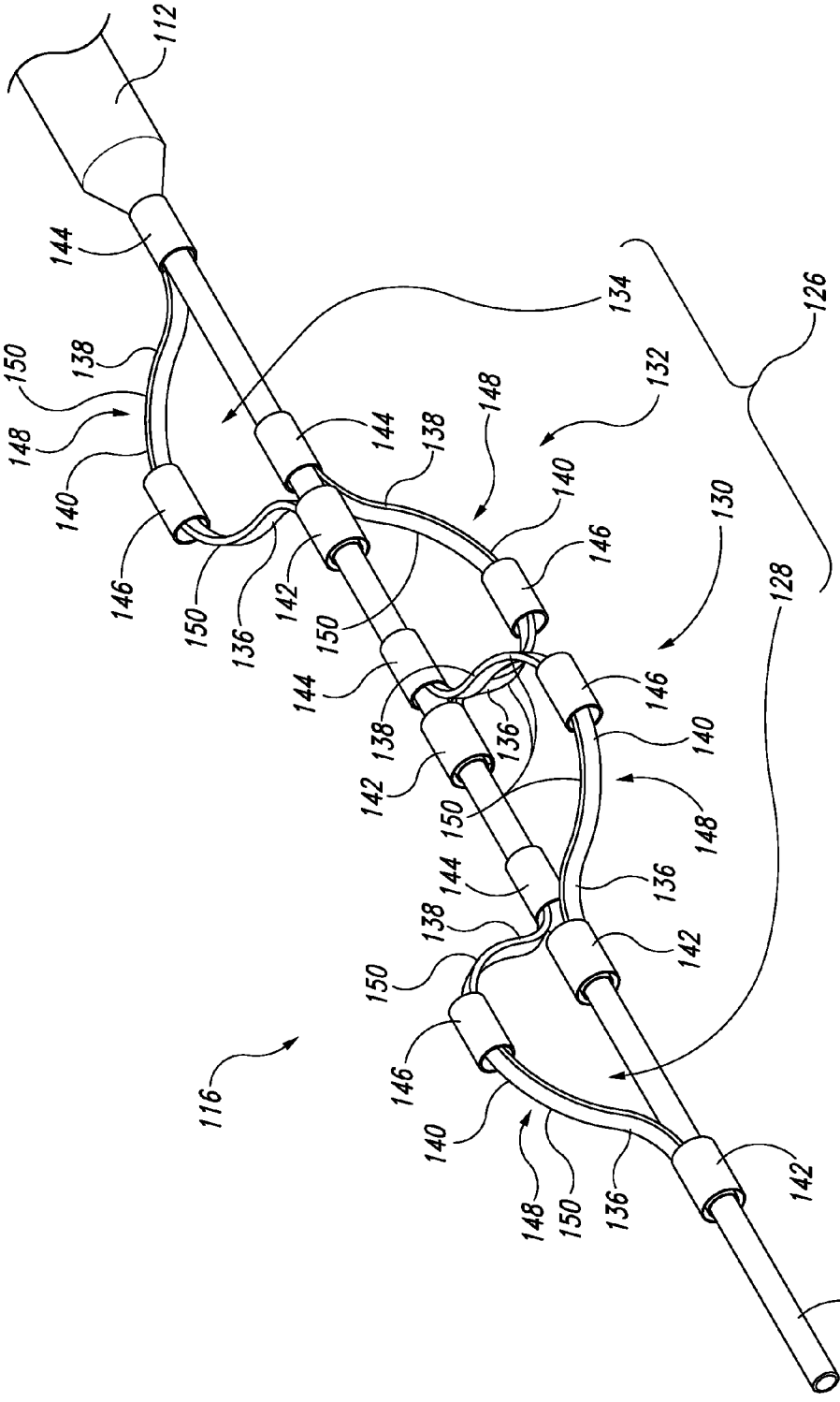
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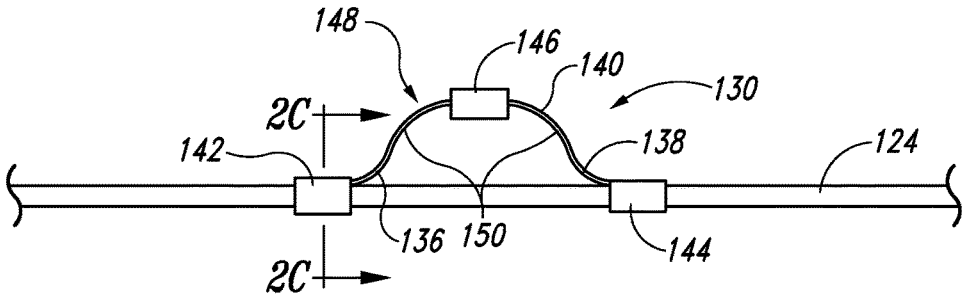
Fig. 1C



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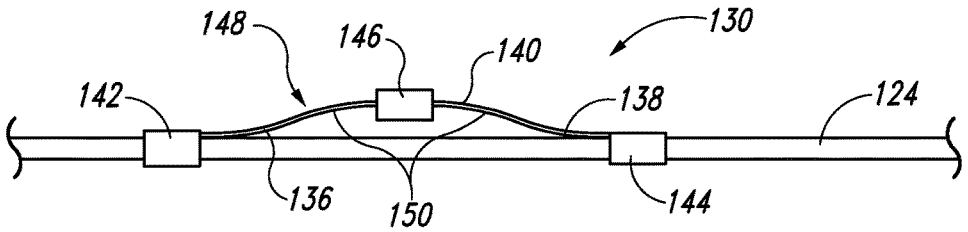

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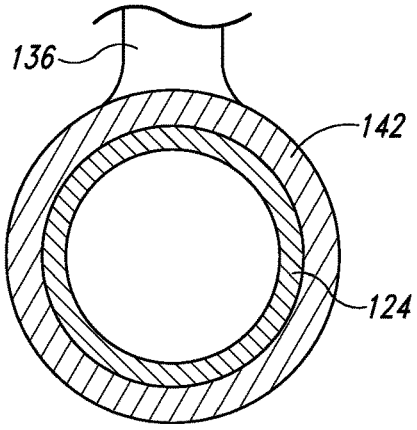

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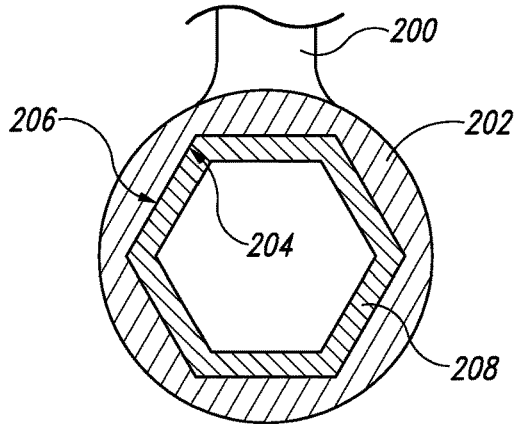

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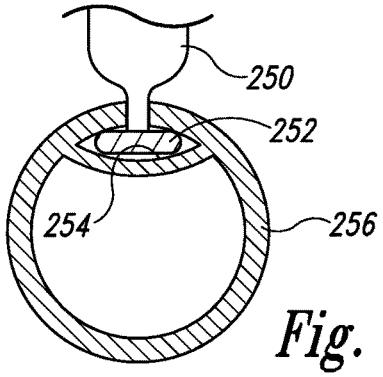

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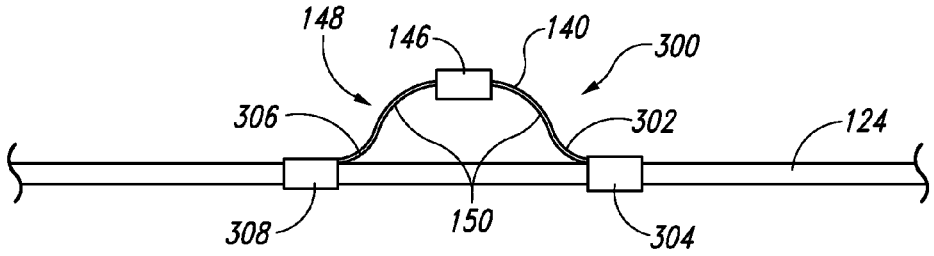

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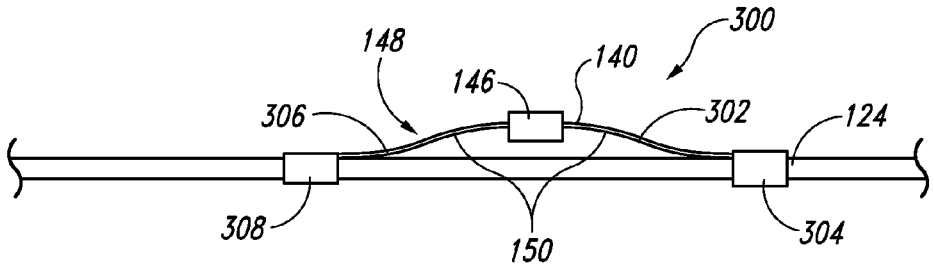

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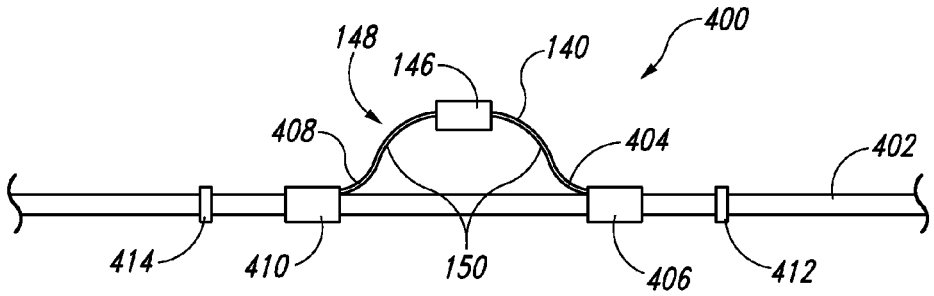

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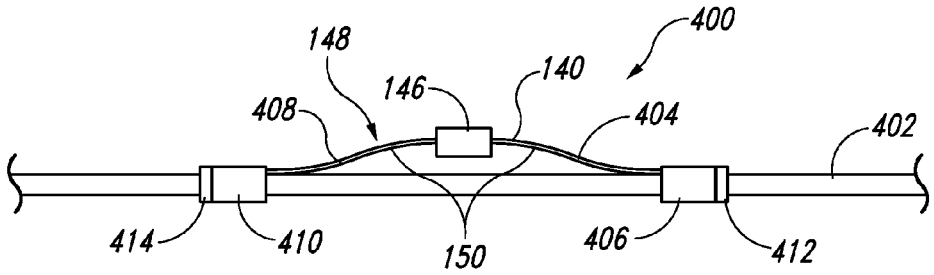

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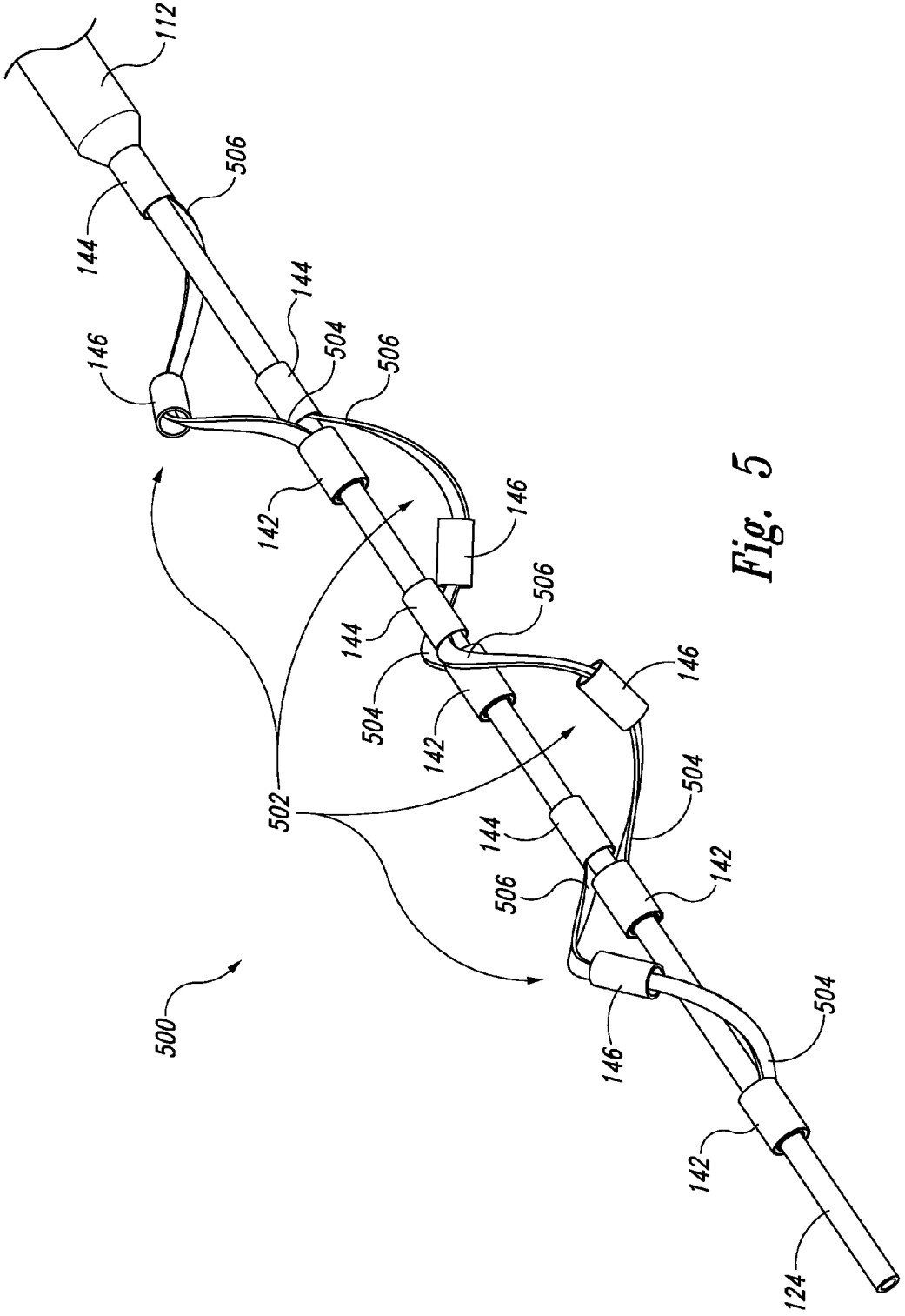
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Fig. 5

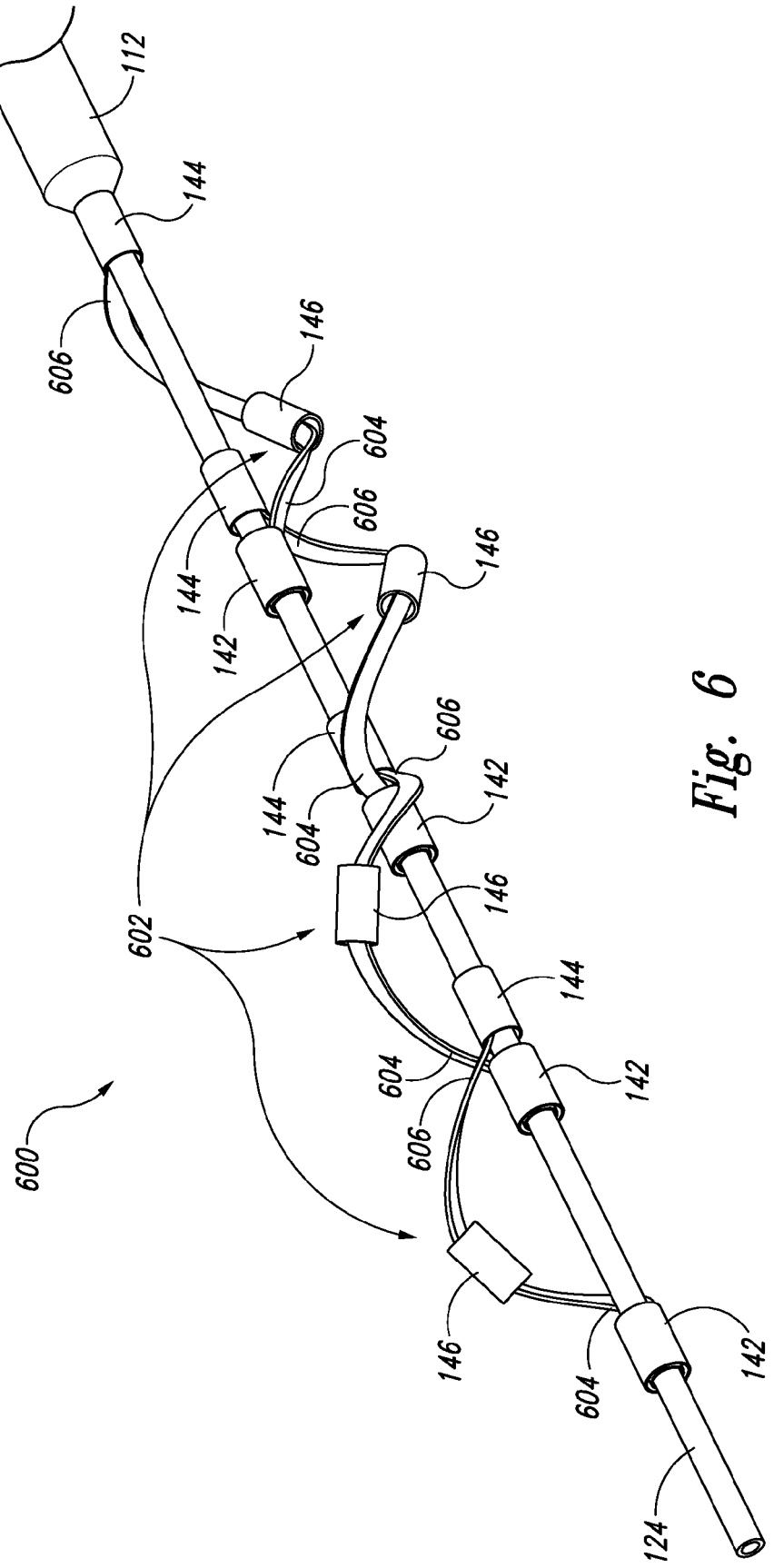
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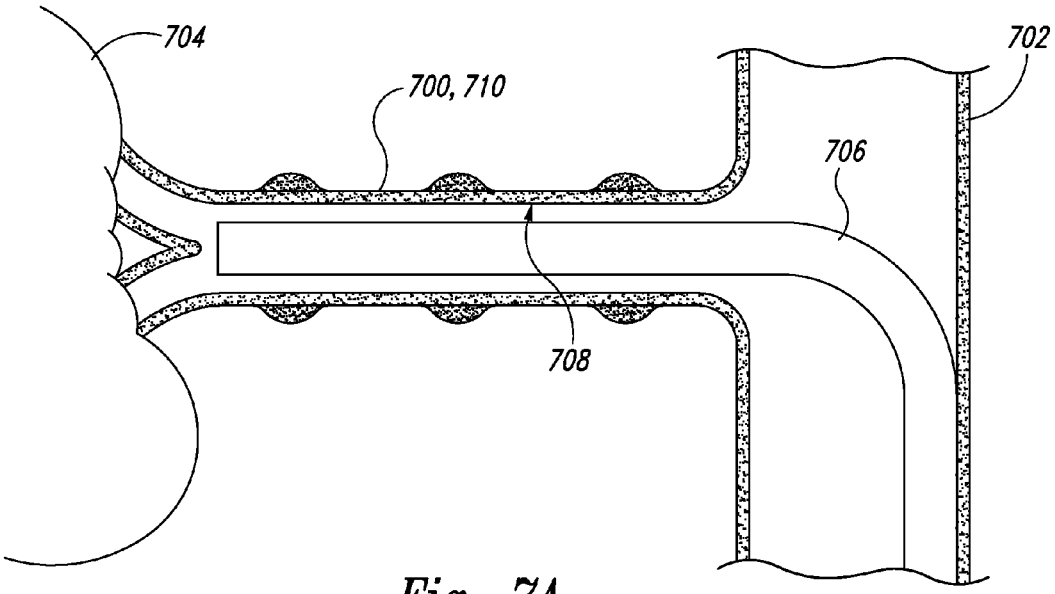
Fig. 6



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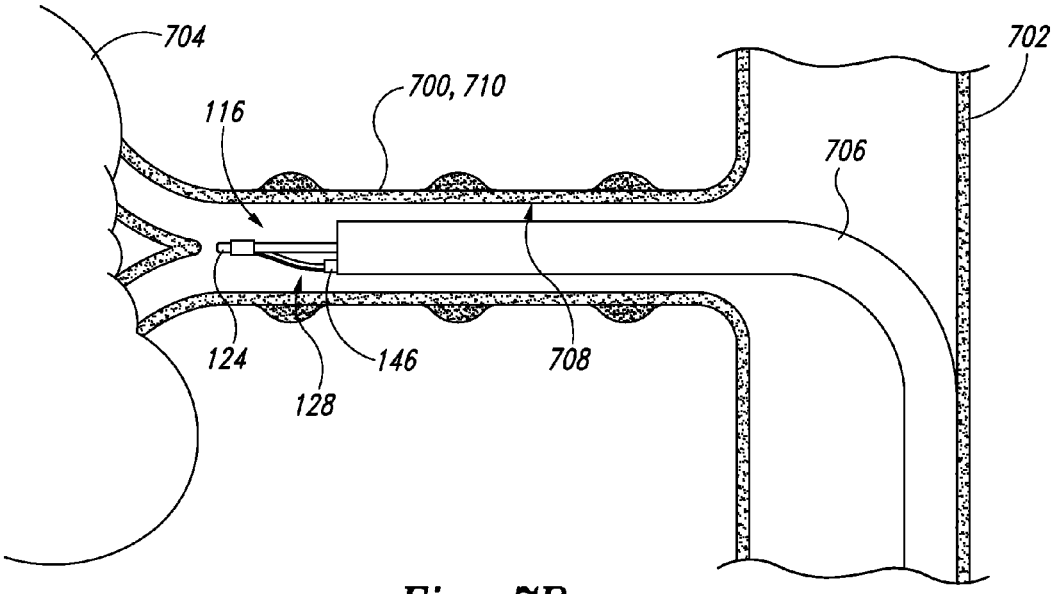

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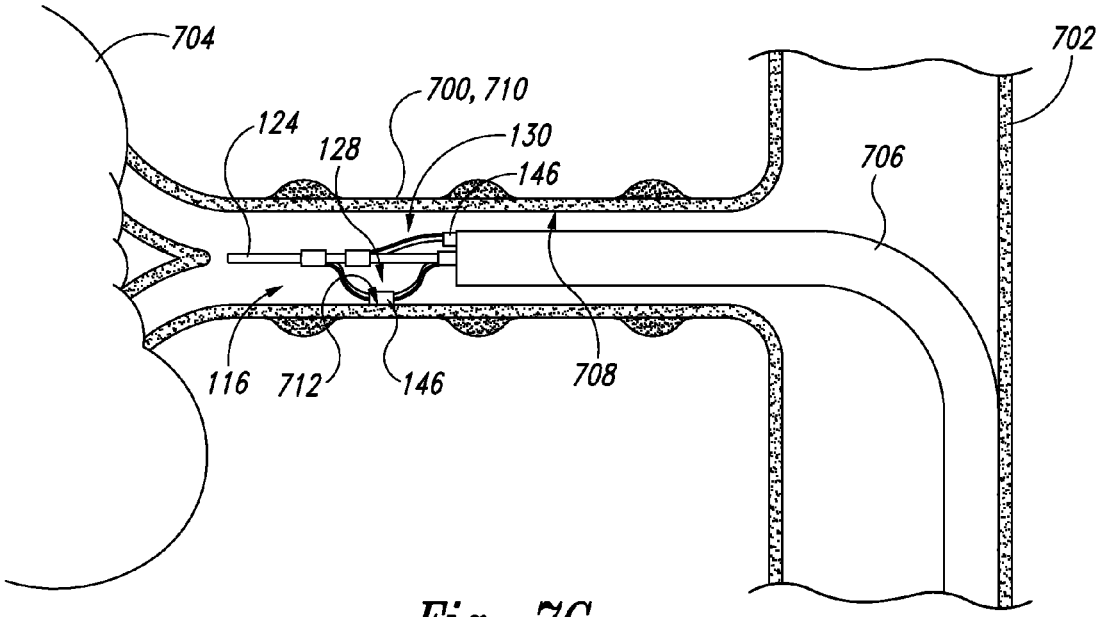
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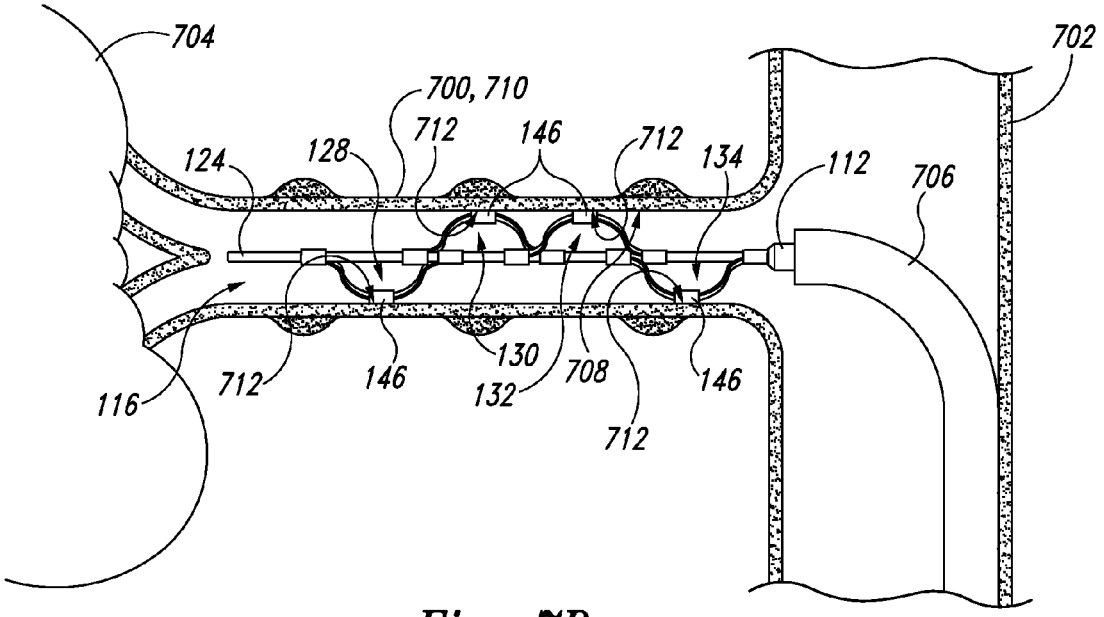
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Fig. 7D

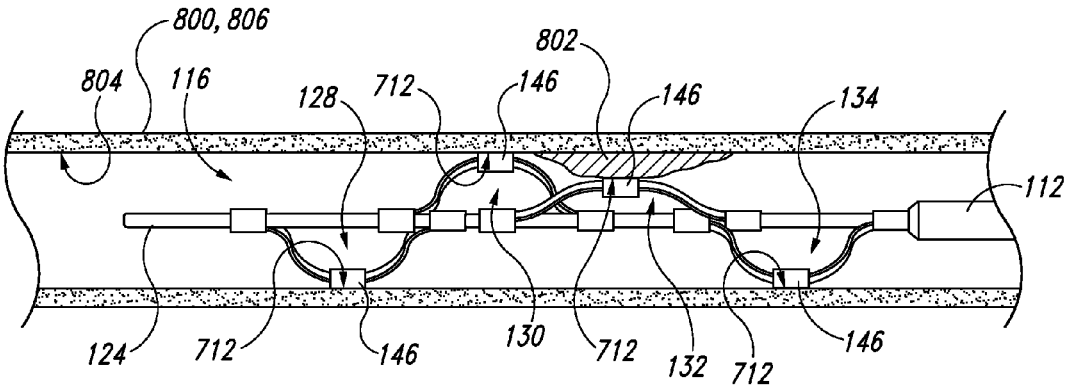
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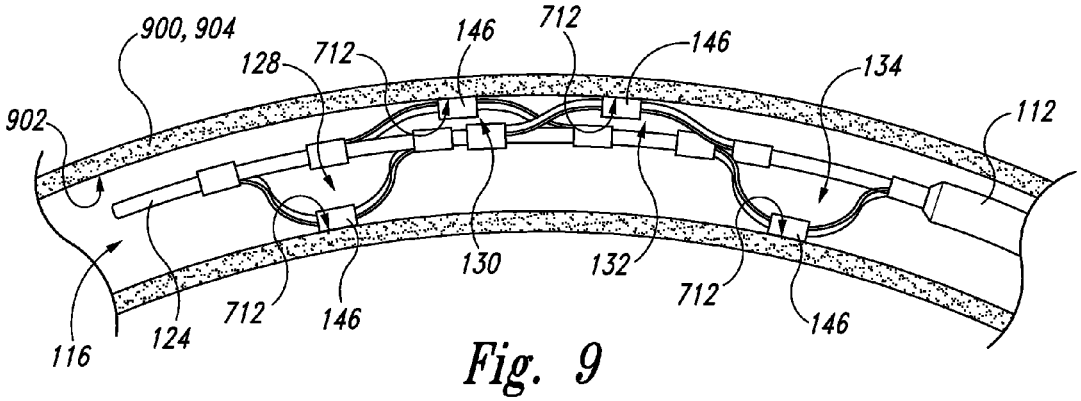
Fig. 8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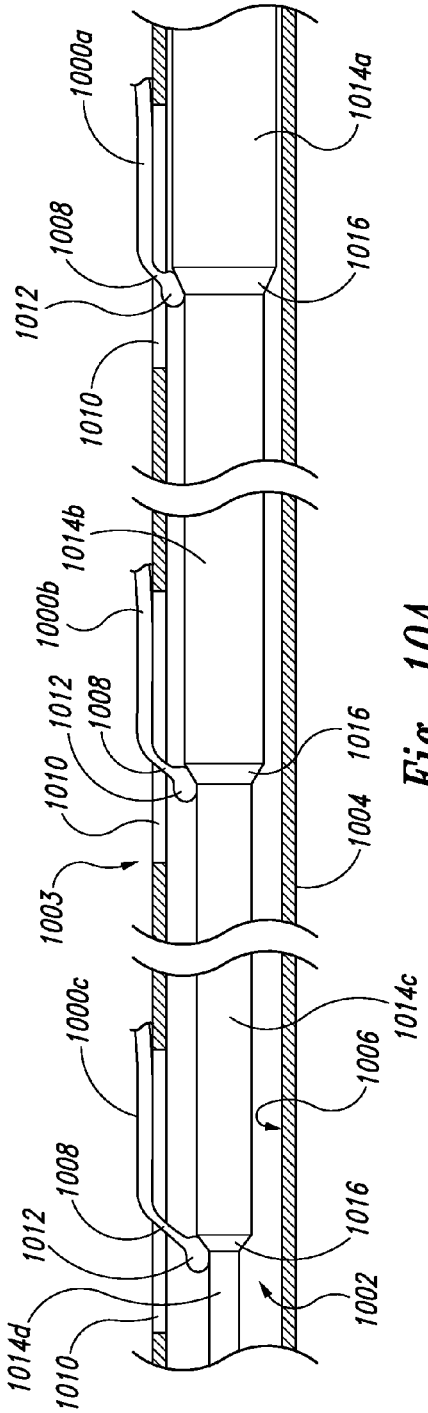

Fig. 10A

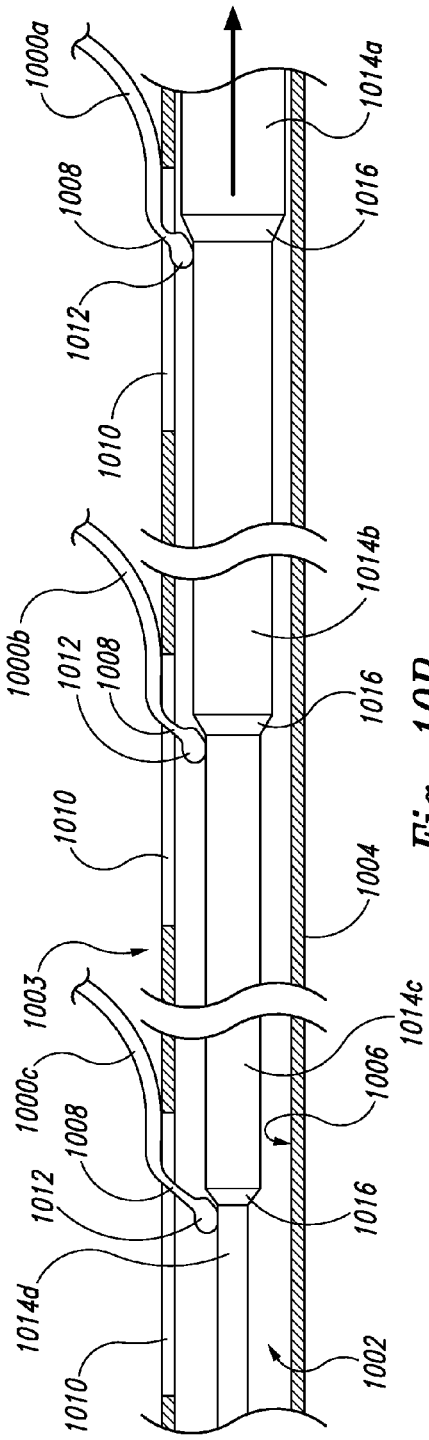

Fig. 10B

CATHETERS WITH INDEPENDENT RADIAL-EXPANSION MEMBERS AND ASSOCIATED DEVICES, SYSTEMS, AND METHODS

TECHNICAL FIELD

The present technology is related to catheters. In particular, at least some embodiments are related to neuromodulation catheters including neuromodulation elements configured to deliver energy to nerves at or near a treatment location within a body lumen.

BACKGROUND

The sympathetic nervous system (SNS) is a primarily involuntary bodily control system typically associated with stress responses. Fibers of the SNS extend through tissue in almost every organ system of the human body and can affect characteristics such as pupil diameter, gut motility, and urinary output. Such regulation can have adaptive utility in maintaining homeostasis or in preparing the body for rapid response to environmental factors. Chronic activation of the SNS, however, is a common maladaptive response that can drive the progression of many disease states. Excessive activation of the renal SNS, in particular, has been identified experimentally and in humans as a likely contributor to the complex pathophysiologies of hypertension, states of volume overload (e.g., heart failure), and progressive renal disease.

Sympathetic nerves of the kidneys terminate in the renal blood vessels, the juxtaglomerular apparatus, and the renal tubules, among other structures. Stimulation of the renal sympathetic nerves can cause, for example, increased renin release, increased sodium reabsorption, and reduced renal blood flow. These and other neural-regulated components of renal function are considerably stimulated in disease states characterized by heightened sympathetic tone. For example, reduced renal blood flow and glomerular filtration rate as a result of renal sympathetic efferent stimulation is likely a cornerstone of the loss of renal function in cardio-renal syndrome (i.e., renal dysfunction as a progressive complication of chronic heart failure). Pharmacologic strategies to thwart the consequences of renal sympathetic stimulation include centrally-acting sympatholytic drugs, beta blockers (e.g., to reduce renin release), angiotensin-converting enzyme inhibitors and receptor blockers (e.g., to block the action of angiotensin II and aldosterone activation consequent to renin release), and diuretics (e.g., to counter renal sympathetic mediated sodium and water retention). These pharmacologic strategies, however, have significant limitations including limited efficacy, compliance issues, side effects, and others.

BRIEF DESCRIPTION OF THE DRAWINGS

Many aspects of the present technology can be better understood with reference to the following drawings. The components in the drawings are not necessarily to scale. Instead, emphasis is placed on illustrating clearly the principles of the present technology. For ease of reference, throughout this disclosure identical reference numbers may be used to identify identical or at least generally similar or analogous components or features.

FIG. **1**A is a perspective view of a system including a catheter, console and cable configured in accordance with an

embodiment of the present technology. The catheter includes an elongated shaft and a therapeutic element operably connected to the shaft.

FIGS. **1**B and **1**C are an enlarged side view and an enlarged perspective view, respectively, of the therapeutic element shown in FIG. **1**A.

FIGS. **2**A and **2**B are side views of a radial-expansion member and an associated segment of a support member of the therapeutic element shown in FIGS. **1**A-**1**C. In FIG. **2**A, the radial-expansion member is shown in a radially expanded state. In FIG. **2**B, the radial-expansion member is shown in a radially constrained state.

FIG. **2**C is an enlarged cross-sectional view of the therapeutic element shown in FIG. **1**A taken along the line **2**C-**2**C in FIG. **2**A.

FIGS. **2**D and **2**E are enlarged cross-sectional views of therapeutic elements of catheters configured in accordance with additional embodiments of the present technology taken along transverse planes similar to the plane corresponding to the line **2**C-**2**C in FIG. **2**A.

FIGS. **3**A and **3**B are side views of a radial-expansion member and an associated segment of a support member of a therapeutic element of a catheter configured in accordance with another embodiment of the present technology. In FIG. **3**A, the radial-expansion member is shown in a radially expanded state. In FIG. **3**B, the radial-expansion member is shown in a radially constrained state.

FIGS. **4**A and **4**B are side views of a radial-expansion member and an associated segment of a support member of a therapeutic element of a catheter configured in accordance with another embodiment of the present technology. In FIG. **4**A, the radial-expansion member is shown in a radially expanded state. In FIG. **4**B, the radial-expansion member is shown in a radially constrained state.

FIGS. **5** and **6** are perspective views of therapeutic elements of catheters configured in accordance with additional embodiments of the present technology.

FIGS. **7**A-**7**D are enlarged anatomical side views of the therapeutic element shown in FIG. **1**A and associated components located at a treatment location within a renal artery. In FIG. **7**A, the therapeutic element is in a low-profile delivery state within a sheath. In FIG. **7**B, the therapeutic element is shown in a first intermediate state as the therapeutic element transitions from the delivery state to a deployed state. In FIG. **7**C, the therapeutic element is shown in a second intermediate state as the therapeutic element transitions from the first intermediate state to the deployed state. In FIG. **7**D, the therapeutic element is shown in the deployed state.

FIG. **8** is an enlarged anatomical side view of the therapeutic element shown in FIG. **1**A in a deployed state and located at a treatment location within a lumen segment including an obstruction.

FIG. **9** is an enlarged anatomical side view of the therapeutic element shown in FIG. **1**A in a deployed state and located at a treatment location within a non-uniform lumen segment.

FIGS. **10**A and **10**B are cross-sectional side views of a series of radial-expansion members and an associated segment of a support member of a therapeutic element of a catheter configured in accordance with another embodiment of the present technology. In FIG. **10**A, the radial-expansion members are shown in radially constrained states. In FIG. **10**B, the radial-expansion member are shown in radially expanded states.

DETAILED DESCRIPTION

The present technology is related to catheters, such as catheters including neuromodulation elements configured to

deliver energy to nerves at or near a treatment location within a body lumen. More specifically, catheters configured in accordance with at least some embodiments of the present technology are expected to treat tissue (e.g., nerves) at or near treatment locations within geometrically irregular (e.g., curved and/or non-cylindrical) segments of body lumens in a reliable and consistent manner. With at least some conventional catheters, geometrical irregularities (e.g., curves, narrowings, and asymmetries, among other examples) of body lumens may complicate the reliable and consistent formation of desirable treatment profiles. For example, in many neuromodulation treatments, it is desirable to form a helical lesion or pattern of lesions, which may allow substantially all nerves around the circumference of a body lumen to be modulated without forming a potentially problematic fully circumferential lesion in any single transverse plane. Other examples of desirable treatment profiles may be non-helical.

Known types of neuromodulation catheters suitable for forming helical lesions or patterns of lesions include a therapeutic element having a resilient or otherwise expandable structure carrying a plurality of electrodes and may be capable of reliably achieving complete deployment within a cylindrical body lumen. In some cases, however, the desired or target body lumen may not be cylindrical. For example, renal neuromodulation can include modulating nerves at or near treatment locations within renal arteries, which are often relatively short and tortuous. When a therapeutic element of a neuromodulation catheter is deployed at a treatment location within a lumen segment that is non-cylindrical (e.g., not straight and/or having an inconsistent cross-sectional area in successive transverse planes), it may be challenging to reliably attain complete deployment of the therapeutic element and thereby achieve simultaneous, stable, and/or otherwise therapeutically effective contact between electrodes carried by the therapeutic element and an inner surface of a wall of a body lumen.

When a therapeutic element is not completely deployed, energizing an electrode carried by the therapeutic element may form an incomplete lesion, such as a lesion that does not penetrate the wall of the body lumen deeply enough to modulate the sympathetic nerve(s) proximate the electrode. To improve the likelihood of forming a complete lesion, a clinician may reposition the therapeutic element until complete deployment of the therapeutic element is achieved, as may be indicated by adequate impedance measured through the electrode. Alternatively, a clinician may compensate for incomplete deployment by forming multiple lesions at different positions on the body lumen. Each of these options is time consuming and may increase the risk of undesirable complications. Furthermore, incomplete deployment of a therapeutic element may go undetected and diminish the therapeutic effect of a neuromodulation treatment.

Neuromodulation catheters configured in accordance with embodiments of the present technology can at least partially address one or more of the problems described above and/or other problems associated with known neuromodulation technologies whether or not stated herein. For example, a neuromodulation catheter configured in accordance with a particular embodiment includes an elongate shaft and a therapeutic element operably connected to the shaft. The therapeutic element includes an elongate support member and a plurality of radial-expansion members operably connected to the support member. The individual radial-expansion members each carry an electrode and are configured to independently expand radially outward from the support member when the therapeutic elements each transition from a low-profile delivery state to a deployed state at a treatment location within a body lumen. The plurality of radial-expansion members is configured to urge the electrodes into contact with an inner surface of a wall of the lumen segment at a series of longitudinally and circumferentially spaced-apart contact regions. The relative independence of the radial expansion of a given radial-expansion member relative to other radial-expansion members on the catheter and/or other features of the neuromodulation catheter may facilitate reliably achieving complete deployment of the therapeutic element. For example, when the therapeutic element is deployed at a treatment location within a lumen segment that is not straight and/or has an inconsistent cross-sectional area in successive transverse planes, the effect of these anatomical characteristics can be localized.

Specific details of several embodiments of the present technology are described herein with reference to FIGS. **1A-10B**. Although many of the embodiments are described herein with respect to devices, systems, and methods for percutaneous intravascular renal neuromodulation, other applications and other embodiments in addition to those described herein are within the scope of the present technology. For example, at least some embodiments may be useful for neuromodulation within a body lumen other than a blood vessel, for extravascular neuromodulation, for non-renal neuromodulation, and/or for use in therapies other than neuromodulation. It should be noted that other embodiments in addition to those disclosed herein are within the scope of the present technology. Furthermore, embodiments of the present technology can have different configurations and components, and may be used for procedures different from those disclosed herein. Moreover, a person of ordinary skill in the art will understand that embodiments of the present technology can have configurations, components, and/or procedures in addition to those disclosed herein and that these and other embodiments can be without several of the configurations, components, and/or procedures disclosed herein without deviating from the present technology.

As used herein, the terms "distal" and "proximal" define a position or direction with respect to a clinician or a clinician's control device (e.g., a handle of a catheter). The terms, "distal" and "distally" refer to a position distant from or in a direction away from a clinician or a clinician's control device. The terms "proximal" and "proximally" refer to a position near or in a direction toward a clinician or a clinician's control device. The headings provided herein are for convenience only and should not be construed as limiting the subject matter disclosed.

Selected Examples of Neuromodulation Catheters and Related Devices

FIG. **1A** is a perspective view of a system **100** (e.g., a neuromodulation system) configured in accordance with an embodiment of the present technology. The system **100** can include a catheter **102** (e.g., a neuromodulation catheter), a console **104**, and a cable **106** extending therebetween. The catheter **102** can include an elongate shaft **108** having a proximal end portion **110** and a distal end portion **112**. The catheter **102** can further include a handle **114** and a therapeutic element **116** (e.g., a neuromodulation element) operably connected to the shaft **108** via, respectively, the proximal and distal end portions **110**, **112** of the shaft **108**. The shaft **108** can be configured to locate the therapeutic element **116** intravascularly at a treatment location within a body lumen, such as a suitable blood vessel, duct, airway, or other naturally occurring lumen within the human body. The

therapeutic element **116** can be configured to provide or support a treatment (e.g., a neuromodulation treatment) at the treatment location.

Therapeutic element **116** can be configured to be radially constrained and slidably disposed within a delivery sheath (see FIGS. **7**A-**7**D) while the catheter **102** is being deployed within a body lumen. The outside diameter of the sheath can be 2, 3, 4, 5, 6, or 7 French or another suitable size. As an example, deployment of the catheter **102** can include percutaneously inserting a medical guide wire (not shown) into a body lumen of a patient and advancing the catheter **102** along the guide wire until the therapeutic element **116** reaches a suitable treatment location. As another example, the catheter **102** can be steerable or non-steerable and configured for deployment without a guide wire. Catheter **102** can also be configured for deployment via a guide catheter (not shown) with or without the use of a delivery sheath or guide wire.

The console **104** can be configured to control, monitor, supply energy, and/or otherwise support operation of the catheter **102**. Alternatively, the catheter **102** can be self-contained or otherwise configured for operation without connection to a console **104**. When present, the console **104** can be configured to generate a selected form and/or magnitude of energy for delivery to tissue at or near a treatment location via the therapeutic element **116**. The console **104** can have different configurations depending on the treatment modality of the catheter **102**. When the catheter **102** is configured for electrode-based, heat-element-based, or transducer-based treatment, for example, the console **104** can include an energy generator (not shown) configured to generate radio frequency (RF) energy (e.g., monopolar and/or bipolar RF energy), pulsed electrical energy, microwave energy, optical energy, ultrasound energy (e.g., intravascularly delivered ultrasound energy, extracorporeally delivered ultrasound energy, and/or high-intensity focused ultrasound energy), direct heat, radiation (e.g., infrared, visible, and/or gamma radiation), and/or another suitable type of energy. Similarly, when the catheter **102** is configured for chemical-based treatment (e.g., drug infusion), the console **104** can include a chemical reservoir (not shown) and can be configured to supply the catheter **102** with one or more chemicals.

In some embodiments, the system **100** includes a control device **118** along the cable **106**. The control device **118** can be configured to initiate, terminate, and/or adjust operation of one or more components of the catheter **102** directly and/or via the console **104**. In other embodiments, the control device **118** can be absent or can have another suitable location, such as within the handle **114**. The console **104** can be configured to execute an automated control algorithm **120** and/or to receive control instructions from an operator. Furthermore, the console **104** can be configured to provide information to an operator before, during, and/or after a treatment procedure via an evaluation/feedback algorithm **122**.

FIGS. **1**B and **1**C are an enlarged side view and an enlarged perspective view, respectively, of the therapeutic element **116**. The therapeutic element **116** can include an elongate support member **124** and a plurality of radial-expansion members **126** operably connected to the support member **124** in a distal-to-proximal sequence. In the illustrated embodiment, the plurality of radial-expansion members **126** includes a first radial-expansion member **128**, a second radial-expansion member **130**, a third radial-expansion member **132**, and a fourth radial-expansion member **134**. It will be appreciated, however, that in other embodiments the therapeutic element **116** may include a different number of individual radial-expansion members **126** (e.g., another suitable number less than 10 or a suitable number greater than 10). The individual radial-expansion members **126** can include a distal end portion **136** (e.g., a distal leg) and a proximal end portion **138** (e.g., a proximal leg). One or both of the distal and proximal end portions **136**, **138** of the individual radial-expansion members **126** can be moveably (e.g., slidably) connected to the support member **124**. Disposed between their respective distal and proximal end portions **136**, **138**, the individual radial-expansion members **126** can include a bridging portion **140** configured to expand radially outward from the support member **124** in conjunction with the corresponding distal end portion **136** moving proximally toward the corresponding proximal end portion **138** and/or the corresponding proximal end portion **138** moving distally toward the corresponding distal end portion **136**.

In the illustrated embodiment, the distal end portions **136** of the individual radial-expansion members **126** include a longitudinally slidable collar **142** mounted about support member **124**. The proximal end portions **138** of the individual radial-expansion members **126** include a fixed collar **144** mounted about support member **124**. Collars **142**, **144** can extend fully or partially around support member **124** or may be replaced with other suitable connecting structures. Also In the illustrated embodiment, individual radial-expansion members each 126 carry an annular electrode **146** at their respective bridging portions **140** and include an electrical lead (not shown) extending along or through their respective proximal end portions **138**. In other embodiments, radial-expansion members **126** can include other suitable types and/or positions of electrodes **146** and associated leads. For example, resilient members **126** can be electrically conductive, with bridging portions **140** serving as electrodes and proximal end portions **138** serving as electrical leads. In still other embodiments, individual radial-expansion members **126** can include treatment elements other than electrodes, such as devices suitable for providing other energy-based or chemical-based treatment modalities.

The individual radial-expansion members **126** can be configured to independently expand radially outward from the support member **124** when the therapeutic element **116** transitions from a low-profile delivery state to a deployed state. For example, the individual radial-expansion members **126** can be resiliently biased to move their respective bridging portions **140** radially outward from the support member **124** when each radial-expansion member **126** is released from the inward radial constraint provided by a delivery sheath. Furthermore, the individual radial-expansion members **126** can be configured to self-expand from a radially constrained, stressed condition in the low-profile delivery state to a radially expanded, relaxed condition at a predetermined extent of radial expansion in the deployed state. The plurality of radial-expansion members **126** can be arranged along support member **124** to urge the electrodes **146** into contact with an inner surface of a lumen wall (not shown) at a series of contact regions when the therapeutic element **116** is in the deployed state at a treatment location within a body lumen having the lumen wall. In this way, the therapeutic element **116** can form a desirable treatment profile. For example, the contact regions can be longitudinally and circumferentially spaced apart and, in at least some cases, disposed along a helical path.

Individual radial-expansion members **126** partially overlap longitudinally. For example, the distal and proximal end

portions **136**, **138** of the plurality of radial-expansion members **126** can be interdigitated and/or the individual radial-expansion members **126** can be longitudinally staggered, nested, and/or interrelated in another suitable manner. This can be useful, for example, to facilitate independent expansion of the individual radial-expansion members **126** without unduly sacrificing longitudinal compactness. The distal end portions **136** of the individual radial-expansion members **126** can be operably connected to the support member **124** at positions between positions at which the distal and proximal end portions **136**, **138** of a distally adjacent radial-expansion member **126** (if present) are operably connected to the support member **124**. For example, the distal end portions **136** of the individual radial-expansion members **126** can be fixedly connected to or longitudinally slidable along segments of the support member **124** between distal and proximal end portions **136**, **138** of a distally adjacent radial-expansion member **126** (if present). Similarly, the proximal end portions **138** of the individual radial-expansion members **126** can be operably connected to the support member **124** at positions between positions at which the distal and proximal end portions **136**, **138** of the proximally adjacent radial-expansion member **126** (if present) are operably connected to the support member **124**. For example, the proximal end portions **138** of the individual radial-expansion members **126** can be fixedly connected to or longitudinally slidable along segments of the support member **124** between distal and proximal end portions **136**, **138** of a proximally adjacent radial-expansion member **126** (if present).

In the illustrated embodiment, the individual radial-expansion members **126** include a bow-shaped ribbon **148** made of metal (e.g., spring tempered stainless steel or titanium nickel alloy commonly known as nitinol) and having sigmoid, i.e. C-shaped, or bell-shaped portions **150** with opposite orientations at opposite sides of the bridging portion **140**. In other embodiments, the radial-expansion members **126** can have other forms suitable for radial expansion to place bridging portions **140** in apposition with the inner wall of a body lumen. For example, the individual radial-expansion members **126** can include a wire (not shown) in place of the ribbon **148**. As another example, the individual radial-expansion members **126** can each include a tubular structure (not shown) in place of the ribbon **148**, such as to facilitate routing electrical leads from the support member **124** to the electrodes **146**. As yet another example, the individual radial-expansion members **126** can include resiliency-enhancing structural features (not shown), such as compact helical or sinusoidal bends along all or a portion of the length of the ribbon **148**. As yet another example, the overall shape of the individual radial-expansion members **126** can be angular rather than curved. Other suitable variations in the characteristics of the individual radial-expansion members **126** are also possible.

FIGS. **2**A and **2**B are side views of the second radial-expansion member **130** and an associated segment of the support member **124** with the other radial-expansion members **126** omitted for clarity of illustration. In FIG. **2**A, the second radial-expansion member **130** is shown in a radially extended state. In FIG. **2**B, the second radial-expansion member **130** is shown in a radially constrained state. As illustrated in FIGS. **2**A and **2**B, the second radial-expansion member **130** can be configured to move between the extended and constrained states by longitudinal movement of the distal end portion **136** along support member **124** while the proximal end portion **138** remains fixed to support member **124**. This can be useful, for example, to facilitate smooth transitioning of the therapeutic element **116** from the deployed state to the low-profile delivery state as the therapeutic element **116** is retracted into a sheath (not shown), such as by reducing or eliminating catching of the radial-expansion members **126** on a distal lip of the sheath.

FIG. **2**C is an enlarged cross-sectional view of the therapeutic element **116** taken along the line **2**C-**2**C in FIG. **2**A. As illustrated in FIG. **2**C, the slidable collar **142** can be configured to slide along an exterior surface of a segment of the support member **124**. FIGS. **2**D and **2**E are enlarged cross-sectional views of therapeutic elements of catheters configured in accordance with additional embodiments of the present technology taken along transverse planes similar to the plane corresponding to the line **2**C-**2**C in FIG. **2**A. As shown in FIG. **2**D, in some embodiments, a distal end portion **200** of a radial-expansion member (not separately identified in FIG. **2**D) includes a slidable collar **202** that has a non-circular inner surface in a transverse plane. The slidable collar **202** and a corresponding outer surface **206** of a support member **208** can be keyed. As shown in FIG. **2**E, in other embodiments, a distal end portion **250** of a radial-expansion member (not separately identified in FIG. **2**E) includes an enlarged head **252** slidably disposed within a channel **254** defined by a support member **256**. The channel **254** can be a common channel that receives heads **252** of distal end portions **250** of multiple radial-expansion members (not shown) or a discrete channel that receives only the head **252** shown in FIG. **2**E. In the latter case, the channel **254** can be one of a plurality of channels that individually receive different heads **252**.

Features of the embodiments shown in FIGS. **2**D and **2**E may restrict circumferential, e.g. rotational movement of the slidable collars **142**, **202** relative to respective support members **208**, **256**. This can be useful, for example, when it is desirable to maintain precise radial orientations s of the distal end portions **200**, **250**, respectively. As another potential advantage, features of the embodiments shown in FIGS. **2**D and **2**E that restrict rotational movement of the distal end portions **200**, **250** relative to the respective support members **208**, **256** may reduce or prevent twisting of leads. Leads and other features (e.g., guide-wire lumens and structural members, among others) within the support members **124**, **208**, **256** are omitted in FIGS. **2**C-**2**E for simplicity of illustration.

FIGS. **3**A-**4**B illustrate movement of radial-expansion members relative to corresponding support members in catheters configured in accordance with additional embodiments of the present technology. As one example, FIGS. **3**A and **3**B are side views of a radial-expansion member **300** and an associated segment of the support member **124** with the radial-expansion member **300** shown in a radially extended state in FIG. **3**A and in a radially constrained state in FIG. **3**B. Unlike the radial-expansion members **126**, the radial-expansion member **300** includes a proximal end portion **302** having a longitudinally slidable collar **304** and a distal end portion **306** having a fixed collar **308**. As another example, FIGS. **4**A and **4**B are side views of a radial-expansion member **400** and an associated segment of a support member **402** with the radial-expansion member **400** shown in a radially extended state in FIG. **4**A and in a radially constrained state in FIG. **4**B. Unlike the radial-expansion members **126**, **300**, the radial-expansion member **400** includes a proximal end portion **404** having a longitudinally slidable collar **406** and a distal end portion **408** having a longitudinally slidable collar **410**. The radial-expansion member **400** can further include a proximal stop **412** and a distal stop **414** fixedly connected to the support member **402** proximal and distal, respectively, to the radial-expansion member **400**. The proximal stop **412** can be positioned to restrict proximal

movement of the proximal end portion **404**. Similarly, the distal stop **414** can be positioned to restrict distal movement of the distal end portion **408**. Other arrangements of stops (not shown) can be envisioned in radial-expansion member **400**, such as one long stop or two short stops positioned between collars **410**, **412** to limit the range of positions that radial-expansion member **400** may take along support member **402** while still permitting the radially extended state shown in FIG. **4**A to be fully attained.

With reference to again FIGS. **1**A-**1**C, in the illustrated embodiment, the individual radial-expansion members **126** are circumferentially offset and longitudinally staggered relative to one another. This arrangement can be such that the therapeutic element **116** has an asymmetrical cross section in each transverse plane intersecting a given bridging portion **140**. The incremental circumferential offset, i.e. the angular offset about support member **124**, from a given radial-expansion member **126** to a proximally successive radial-expansion member **126** can be 90 degrees. For example, looking proximally from a distal end of the support member **124**, the first radial-expansion member **128** can be oriented at 12 o'clock (0 degrees), the second radial-expansion member **130** can be oriented at 3 o'clock (90 degrees), the third radial-expansion member **132** can be oriented at 6 o'clock (180 degrees), and the fourth radial-expansion member **134** can be oriented at 9 o'clock (270 degrees). In other embodiments, the circumferential offset can be greater than 90 degrees (e.g., within a range from 90 degrees to 180 degrees) or less than 90 degrees (e.g., within a range from 5 degrees to 90 degrees).

In some embodiments, the individual radial-expansion members **126** are planar with the distal and proximal end portions **136**, **138** of a given radial-expansion member **126** having the same radial orientation relative to the support member **124**. In other embodiments, the individual radial-expansion members **126** can be non-planar and the distal and proximal end portions **136**, **138** of a given radial-expansion member **126** can have different radial orientations relative to the support member **124**. FIGS. **5** and **6**, for example, illustrate examples of non-planar radial-expansion members of therapeutic elements of catheters configured in accordance with additional embodiments of the present technology. FIG. **5** is a perspective view of a therapeutic element **500** including a plurality of non-planar radial-expansion members **502** that are twisted such that distal and proximal end portions **504**, **506** of a given radial-expansion member **502** are circumferentially offset from one another. This can be useful, for example, to enhance alignment of the electrodes **146** with a desirable treatment profile, such as a helical treatment profile.

Similar to the therapeutic element **116** shown in FIG. **1**A, in the embodiment shown in FIG. **5**, the radial-expansion members **502** are circumferentially fully offset from one another. In contrast, FIG. **6** is a perspective view of a therapeutic element **600** including non-planar radial-expansion members **602** that are circumferentially interwoven. The radial-expansion members **602** can extend away from the support member **124** along one side of distally neighboring radial-expansion member **602** and twist back toward the support member along an opposite side of a proximally neighboring radial-expansion member **602**. In other words, the distal end portion **604** of a given radial-expansion member **602** can be circumferentially offset to one side of a proximal end portion **606** of a distally neighboring radial-expansion member **602** while the proximal end portion **606** of the given radial-expansion member **602** is circumferentially offset to the opposite side of a distal end portion **604**[KM1] of a proximally neighboring radial-expansion member **602**. This can be useful, to further enhance alignment of the electrodes **146** with a desirable treatment profile, such as a helical treatment profile. For example, circumferentially interweaving the radial-expansion members **602** may reduce or prevent interference between neighboring radial-expansion member **602** during expansion and contraction even when the radial-expansion members **602** are sharply twisted. In other embodiments, radial-expansion members can have other suitable configurations.

FIGS. **7**A-**7**D are enlarged anatomical side views of the therapeutic element **116** shown in FIG. **1**A and associated components being used for renal neuromodulation at a treatment site within a renal artery **700** that extends between an aorta **702** and a kidney **704** in a human patient. The therapeutic element **116** can also be used for other purposes and at treatment locations within other suitable body lumens. To locate the therapeutic element **116** at the treatment location, the catheter **102** can be advanced toward the treatment location while the therapeutic element **116** is radially constrained in a low-profile delivery state within a delivery sheath **706**. In FIG. **7**A, the therapeutic element **116** is in the delivery state hidden within the sheath **706**. It will be understood by persons familiar with the field of catheterization that catheter **102** and sheath **706** would typically be guided, simultaneously or separately, from a vascular puncture site to renal artery **700** using a guiding catheter and/or a medical guidewire, both of which are omitted from FIGS. **7**A-**7**D for simplicity of illustration.

In FIG. **7**B, the therapeutic element **116** is shown in a first intermediate state as it transitions from the delivery state to a deployed state. Sheath **706** is shown as having been withdrawn from renal artery **700** sufficiently to expose only a distal portion of first radial expansion member **128**, which remains radially constrained by delivery sheath **706**. In FIG. **7**C, the therapeutic element **116** is shown in a second intermediate state as it transitions from the first intermediate state to the deployed state. Sheath **706** is shown as having been withdrawn from renal artery **700** sufficiently to expose all of first radial expansion member **128**, which has self-expanded into apposition with inner surface **708** of a wall **710** of the renal artery **700**. As shown in FIGS. **7**B and **7**C, deploying the therapeutic element **116** can include independently expanding the radial-expansion members **128**, **130**, **132**, **134** one at a time in a distal-to-proximal sequence. This can include retracting the sheath **706** relative to the catheter **102** (FIG. **1**A) and/or advancing the catheter **102** relative to the sheath **706** so as to allow the unconstrained radial-expansion members **126** to resiliently urge the electrodes **146** toward an inner surface **708** of a wall **710** of the renal artery **700**. In FIG. **7**D, the therapeutic element **116** is shown in the deployed state. Sheath **706** is shown as having been withdrawn from renal artery **700** sufficiently to expose all radial expansion members **128**, **130**, **132**, **134**, which have self-expanded into apposition with inner surface **708** of a wall **710** of the renal artery **700**. In the embodiment shown, radial expansion members **128**, **130**, **132**, **134** are configured such that electrodes **146** form a series of longitudinally and circumferentially spaced-apart contact regions **712** disposed along a helical path. After therapeutic element **116** is deployed at the treatment location, electrodes **146** can be energized to modulate one or more nerves at or near the treatment location.

As discussed above, catheters configured in accordance with at least some embodiments of the present technology are expected to treat tissue (e.g., nerves) at or near treatment locations within geometrically irregular (e.g., non-cylindri-

cal) segments of body lumens in a reliable and consistent manner. For example, FIG. **8** is an enlarged anatomical side view of the therapeutic element **116** in the deployed state and located at a treatment location within a lumen segment **800** including an obstruction **802**. As shown in FIG. **8**, the obstruction **802** is expected to partially inhibit full radial expansion of some, but not all, of the radial-expansion members **126**, such as the third radial-expansion member **132** only. This, however, is expected to have little or no effect on radial expansion of the other radial-expansion members **126** or on the ability of the therapeutic element **116** to achieve stable contact between the electrodes **146** and an inner surface **804** of a wall **806** of the lumen segment **800**.

As another example, FIG. **9** is an enlarged anatomical side view of the therapeutic element **116** in the deployed state and located at a treatment location within a curved lumen segment **900**. As shown in FIG. **9**, the curve is expected to urge the support member **124** away from the center of the lumen segment **900** and thereby partially inhibit full radial expansion of some, but not all, of the radial-expansion members **126**, such as the second and third radial-expansion members **130**, **132** only. This, however, is expected to have little or no effect on the radial expansion of the other radial-expansion members **126** or on the ability of the therapeutic element **116** to achieve stable contact between the electrodes **146** and an inner surface **902** of a wall **904** of the lumen segment **900**. The behavior illustrated in FIGS. **8** and **9** is by way of theory only and is not intended to limit the scope of the present technology. The therapeutic element **116** may behave differently in practice and may have the same or different advantages. Furthermore, the therapeutic element **116** may have advantages entirely distinct from the advantages described with reference to FIGS. **8** and **9**.

As discussed above with reference to FIGS. **7**A-**7**D, in some embodiments, radial-expansion members are configured to expand one at a time in a distal-to-proximal sequence. In other embodiments, radial-expansion members can be configured to expand in another suitable manner, such as simultaneously. FIGS. **10**A-**10**B illustrate three radial-expansion members **1000** (individually identified as radial-expansion members **1000***a-c*) configured to be exposed from within a sheath (not shown) and then expanded (e.g., simultaneously expanded) by retraction of a control member **1002**. The radial-expansion members **1000** can be operably connected to a support element **1003** including a tube **1004** defining a lumen **1006**. For clarity of illustration, only distal portions of the respective radial-expansion members **1000** are shown in FIGS. **10**A-**10**B. At their respective distal portions, the radial-expansion members **1000** can include a neck **1008**. The tube **1004** can include a series of slots **1010** through which the individual necks **1008** respectively extend. The individual radial-expansion members **1000** can further include a nub **1012** connected to a distal end of the neck **1008**. Proximal end portions (not shown) of the radial-expansion members **1000** can be fixedly connected to the tube **1004**. The individual radial-expansion members **1000** can have different circumferential positions about a longitudinal axis of the support element **1003**. In FIGS. **10**A-**10**B, however, the individual radial-expansion members **1000** are shown in the same plane for clarity of illustration.

The control member **1002** can be slidably received within the lumen **1006**. In the illustrated embodiment, the control member **1002** includes a series of stepped-down segments **1014** (individually identified as stepped-down segments **1014***a-d*) arranged from proximal to distal with successively decreasing diameters. The control member **1002** can further include shoulders or beveled ledges **1016** individually positioned between longitudinally neighboring pairs of the stepped-down segments **1014**. A guide-wire lumen (not shown) can extend longitudinally through a central region of the control member **1002**, such as in alignment with the distalmost stepped-down segment **1014***d*. In at least some other embodiments, the control member **1002** has a more consistent diameter, such as a diameter equal to the diameter of the distalmost stepped-down segment **1014***d*. In these embodiments, for example, the control member **1002** can include longitudinally spaced apart rings or other circumferential enlargements (not shown) arranged from proximal to distal with successively increasing diameters. This can be useful, for example, to increase the flexibility of the control member **1002**.

In FIGS. **10**A and **10**B, the radial-expansion members **1000** are shown in radially constrained states and radially expanded states, respectively. During delivery to a treatment location, the control member **1002** can hold the radial-expansion members **1000** in the radially constrained states. For example, the control member **1002** can be at a distally advanced position with the beveled ledges **1016** respectively pressing against the nubs **1012** to hold the radial-expansion members **1000** in the radially constrained states. The radial-expansion members **1000** can be resiliently biased toward the radially expanded states. To expand the radial-expansion members **1000**, the control member **1002** can be refracted proximally to release constraint on the radial-expansion members **1000** and thereby allow the radial-expansion members **1000** to assume the radially constrained states.

The distal necks **1008**, the nubs **1012**, or both, can be configured to interact with (e.g., to catch) different respective beveled ledges **1016**. This can facilitate independent expansion of the radial-expansion members **1000**. For example, the distal necks **1008** can have successively increasing lengths from proximal to distal so as to align the nubs **1012** with respective beveled ledges **1016**. Alternatively or in addition, the nubs **1012** can have successively increasing sizes from proximal to distal so as to catch different respective beveled ledges **1016**. As the control member **1002** is refracted proximally, any stepped-down segments **1014** distal to a given beveled ledge **1016** aligned with a given nub **1012** can pass by the given nub **1012** without restricting the corresponding radial-expansion member **1000** from moving into its radially constrained state, such as due to the presence of an obstruction or a curve in a lumen segment within which the radial-expansion member **1000** is positioned. This can facilitate the independent operation of the radial-expansion member **1000**.

Renal Neuromodulation

Catheters configured in accordance with at least some embodiments of the present technology can be well suited (e.g., with respect to sizing, flexibility, operational characteristics, and/or other attributes) for performing renal neuromodulation in human patients. Renal neuromodulation is the partial or complete incapacitation or other effective disruption of nerves of the kidneys (e.g., nerves terminating in the kidneys or in structures closely associated with the kidneys). In particular, renal neuromodulation can include inhibiting, reducing, and/or blocking neural communication along neural fibers (e.g., efferent and/or afferent neural fibers) of the kidneys. Such incapacitation can be long-term (e.g., permanent or for periods of months, years, or decades) or short-term (e.g., for periods of minutes, hours, days, or weeks). Renal neuromodulation is expected to contribute to the systemic reduction of sympathetic tone or drive and/or to benefit at least some specific organs and/or other bodily structures innervated by sympathetic nerves. Accordingly,

renal neuromodulation is expected to be useful in treating clinical conditions associated with systemic sympathetic overactivity or hyperactivity, particularly conditions associated with central sympathetic overstimulation. For example, renal neuromodulation is expected to efficaciously treat hypertension, heart failure, acute myocardial infarction, metabolic syndrome, insulin resistance, diabetes, left ventricular hypertrophy, chronic and end stage renal disease, inappropriate fluid retention in heart failure, cardio-renal syndrome, polycystic kidney disease, polycystic ovary syndrome, osteoporosis, erectile dysfunction, and sudden death, among other conditions.

Renal neuromodulation can be electrically-induced, thermally-induced, chemically-induced, or induced in another suitable manner or combination of manners at one or more suitable treatment locations during a treatment procedure. The treatment location can be within or otherwise proximate to a renal lumen (e.g., a renal artery, a ureter, a renal pelvis, a major renal calyx, a minor renal calyx, or another suitable structure), and the treated tissue can include tissue at least proximate to a wall of the renal lumen. For example, with regard to a renal artery, a treatment procedure can include modulating nerves in the renal plexus, which lay intimately within or adjacent to the adventitia of the renal artery. Various suitable modifications can be made to the catheters described above to accommodate different treatment modalities. For example, the electrodes **146** (FIG. **1**B) can be replaced with transducers to facilitate transducer-based treatment modalities. As another example, the electrodes **146** can be replaced with drug-delivery elements (e.g., needles) to facilitate chemical-based treatment modalities. Other suitable modifications are also possible.

Renal neuromodulation can include an electrode-based or treatment modality alone or in combination with another treatment modality. Electrode-based or transducer-based treatment can include delivering electricity and/or another form of energy to tissue at or near a treatment location to stimulate and/or heat the tissue in a manner that modulates neural function. For example, sufficiently stimulating and/or heating at least a portion of a sympathetic renal nerve can slow or potentially block conduction of neural signals to produce a prolonged or permanent reduction in renal sympathetic activity. A variety of suitable types of energy can be used to stimulate and/or heat tissue at or near a treatment location. For example, neuromodulation in accordance with embodiments of the present technology can include delivering RF energy, pulsed electrical energy, microwave energy, optical energy, focused ultrasound energy (e.g., high-intensity focused ultrasound energy), and/or another suitable type of energy. An electrode or transducer used to deliver this energy can be used alone or with other electrodes or transducers in a multi-electrode or multi-transducer array.

Neuromodulation using focused ultrasound energy (e.g., high-intensity focused ultrasound energy) can be beneficial relative to neuromodulation using other treatment modalities. Focused ultrasound is an example of a transducer-based treatment modality that can be delivered from outside the body. Focused ultrasound treatment can be performed in close association with imaging (e.g., magnetic resonance, computed tomography, fluoroscopy, ultrasound (e.g., intravascular or intraluminal), optical coherence tomography, or another suitable imaging modality). For example, imaging can be used to identify an anatomical position of a treatment location (e.g., as a set of coordinates relative to a reference point). The coordinates can then entered into a focused ultrasound device configured to change the power, angle, phase, or other suitable parameters to generate an ultrasound focal zone at the location corresponding to the coordinates. The focal zone can be small enough to localize therapeutically-effective heating at the treatment location while partially or fully avoiding potentially harmful disruption of nearby structures. To generate the focal zone, the ultrasound device can be configured to pass ultrasound energy through a lens, and/or the ultrasound energy can be generated by a curved transducer or by multiple transducers in a phased array, which can be curved or straight.

Heating effects of electrode-based or transducer-based treatment can include ablation and/or non-ablative alteration or damage (e.g., via sustained heating and/or resistive heating). For example, a treatment procedure can include raising the temperature of target neural fibers to a target temperature above a first threshold to achieve non-ablative alteration, or above a second, higher threshold to achieve ablation. The target temperature can be higher than about body temperature (e.g., about 37° C.) but less than about 45° C. for non-ablative alteration, and the target temperature can be higher than about 45° C. for ablation. Heating tissue to a temperature between about body temperature and about 45° C. can induce non-ablative alteration, for example, via moderate heating of target neural fibers or of luminal structures that perfuse the target neural fibers. In cases where luminal structures are affected, the target neural fibers can be denied perfusion resulting in necrosis of the neural tissue. Heating tissue to a target temperature higher than about 45° C. (e.g., higher than about 60° C.) can induce ablation, for example, via substantial heating of target neural fibers or of luminal structures that perfuse the target fibers. In some patients, it can be desirable to heat tissue to temperatures that are sufficient to ablate the target neural fibers or the luminal structures, but that are less than about 90° C. (e.g., less than about 85° C., less than about 80° C., or less than about 75° C.).

Renal neuromodulation can include a chemical-based treatment modality alone or in combination with another treatment modality. Neuromodulation using chemical-based treatment can include delivering one or more chemicals (e.g., drugs or other agents) to tissue at or near a treatment location in a manner that modulates neural function. The chemical, for example, can be selected to affect the treatment location generally or to selectively affect some structures at the treatment location over other structures. The chemical, for example, can be guanethidine, ethanol, phenol, a neurotoxin, or another suitable agent selected to alter, damage, or disrupt nerves. A variety of suitable techniques can be used to deliver chemicals to tissue at or near a treatment location. For example, chemicals can be delivered via one or more needles originating outside the body or within the vasculature or other body lumens. In an intravascular example, a catheter can be used to intravascularly position a therapeutic element including a plurality of needles (e.g., micro-needles) that can be retracted or otherwise blocked prior to deployment. In other embodiments, a chemical can be introduced into tissue at or near a treatment location via simple diffusion through a body lumen wall, electrophoresis, or another suitable mechanism. Similar techniques can be used to introduce chemicals that are not configured to cause neuromodulation, but rather to facilitate neuromodulation via another treatment modality.

CONCLUSION

This disclosure is not intended to be exhaustive or to limit the present technology to the precise forms disclosed herein. Although specific embodiments are disclosed herein for

illustrative purposes, various equivalent modifications are possible without deviating from the present technology, as those of ordinary skill in the relevant art will recognize. In some cases, well-known structures and functions have not been shown and/or described in detail to avoid unnecessarily obscuring the description of the embodiments of the present technology. Although steps of methods may be presented herein in a particular order, in alternative embodiments the steps may have another suitable order. Similarly, certain aspects of the present technology disclosed in the context of particular embodiments can be combined or eliminated in other embodiments. Furthermore, while advantages associated with certain embodiments may have been disclosed in the context of those embodiments, other embodiments may also exhibit such advantages, and not all embodiments need necessarily exhibit such advantages or other advantages disclosed herein to fall within the scope of the present technology. Accordingly, this disclosure and associated technology can encompass other embodiments not expressly shown and/or described herein.

Certain aspects of the present technology may take the form of computer-executable instructions, including routines executed by a controller or other data processor. In some embodiments, a controller or other data processor is specifically programmed, configured, and/or constructed to perform one or more of these computer-executable instructions. Furthermore, some aspects of the present technology may take the form of data (e.g., non-transitory data) stored or distributed on computer-readable media, including magnetic or optically readable and/or removable computer discs as well as media distributed electronically over networks. Accordingly, data structures and transmissions of data particular to aspects of the present technology are encompassed within the scope of the present technology. The present technology also encompasses methods of both programming computer-readable media to perform particular steps and executing the steps.

The methods disclosed herein include and encompass, in addition to methods of practicing the present technology (e.g., methods of making and using the disclosed devices and systems), methods of instructing others to practice the present technology. For example, a method in accordance with a particular embodiment includes advancing an elongate shaft of a neuromodulation catheter toward a treatment location within a body lumen of a human patient while a neuromodulation element of the catheter is in a low-profile delivery state, independently expanding a series of bow springs of the neuromodulation element one at a time in a distal-to-proximal sequence as the neuromodulation element transitions from the delivery state to a deployed state at the treatment location, and energizing electrodes and/or transducers carried by the bow springs to modulate one or more nerves of the patient while the neuromodulation element is at the treatment location and in the deployed state. A method in accordance with another embodiment includes instructing such a method.

Throughout this disclosure, the singular terms "a," "an," and "the" include plural referents unless the context clearly indicates otherwise. Similarly, unless the word "or" is expressly limited to mean only a single item exclusive from the other items in reference to a list of two or more items, then the use of "or" in such a list is to be interpreted as including (a) any single item in the list, (b) all of the items in the list, or (c) any combination of the items in the list. Additionally, the terms "comprising" and the like are used throughout this disclosure to mean including at least the recited feature(s) such that any greater number of the same feature(s) and/or one or more additional types of features are not precluded. Directional terms, such as "upper," "lower," "front," "back," "vertical," and "horizontal," may be used herein to express and clarify the relationship between various elements. It should be understood that such terms do not denote absolute orientation. Reference herein to "one embodiment," "an embodiment," or similar formulations means that a particular feature, structure, operation, or characteristic described in connection with the embodiment can be included in at least one embodiment of the present technology. Thus, the appearances of such phrases or formulations herein are not necessarily all referring to the same embodiment. Furthermore, various particular features, structures, operations, or characteristics may be combined in any suitable manner in one or more embodiments of the present technology.

I claim:

1. A neuromodulation catheter, comprising:
an elongate shaft; and
a neuromodulation element operably connected to the shaft, the neuromodulation element including—
an elongate support member, and
a plurality of bow springs operably connected to the support member, the individual bow springs including a distal leg and a proximal leg, the distal and proximal legs of the plurality of bow springs being longitudinally interdigitated,
wherein the individual bow springs are configured to independently expand radially outward from the support member when the neuromodulation element transitions from a low-profile delivery state to a deployed state.

2. The neuromodulation catheter of claim **1** wherein the distal and proximal legs of the individual bow springs have the same radial orientation relative to the support member.

3. The neuromodulation catheter of claim **1** wherein the distal and proximal legs of the individual bow springs have different radial orientations relative to the support member.

4. The neuromodulation catheter of claim **3** wherein the plurality of bow springs is circumferentially interwoven.

5. The neuromodulation catheter of claim **1** wherein the individual bow springs are self-expanding.

6. The neuromodulation catheter of claim **1** wherein:
the shaft is configured to locate the neuromodulation element at a treatment location within a body lumen having a lumen wall,
the individual bow springs carry or otherwise include an electrode and/or a transducer between their respective distal and proximal legs, and
the plurality of bow springs is configured to urge the electrodes and/or the transducers into contact with an inner surface of the lumen wall at a series of longitudinally and circumferentially spaced-apart contact regions when the neuromodulation element is in the deployed state at the treatment location.

7. The neuromodulation catheter of claim **6** wherein the contact regions are disposed along a helical path.

8. The neuromodulation catheter of claim **1** wherein:
the plurality of bow springs includes a first bow spring, a second bow spring, and a third bow spring, respectively positioned in a distal-to-proximal sequence;
the distal leg of the second bow spring is longitudinally slidable along a segment of the support member between the distal and proximal legs of the first bow spring; and

the distal leg of the third bow spring is longitudinally slidable along a segment of the support member between the distal and proximal legs of the second bow spring.

9. The neuromodulation catheter of claim **8** wherein:

the proximal leg of the first bow spring is longitudinally slidable along a segment of the support member between the distal and proximal legs of the second bow spring; and

the proximal leg of the second bow spring is longitudinally slidable along a segment of the support member between the distal and proximal legs of the third bow spring.

10. The neuromodulation catheter of claim **8** wherein:

the proximal leg of the first bow spring is fixedly connected to the support member between the distal and proximal legs of the second bow spring; and

the proximal leg of the second bow spring is fixedly connected to the support member between the distal and proximal legs of the third bow spring.

11. The neuromodulation catheter of claim **8** wherein the distal legs of the second and third bow springs individually include a fully or partially circumferential collar configured to slide along an exterior surface of the respective segment of the support member.

12. The neuromodulation catheter of claim **11** wherein the collars and the corresponding exterior surfaces of the support member are keyed to restrict rotation of the collars relative to the support member.

13. The neuromodulation catheter of claim **8** wherein the distal legs of the second and third bow springs individually include an enlarged head slidably disposed within a single channel or, respectively, within different channels defined by the support member.

14. A neuromodulation catheter comprising:

an elongate shaft; and

a neuromodulation element operably connected to the shaft, the neuromodulation element including—

an elongate support member,

a first radial-expansion member having—

a first distal end portion operably connected to the support member at a first position along a length of the support member,

a first proximal end portion operably connected to the support member at a second position along the length of the support member, and

a first bridging portion extending between the first distal end portion and the first proximal end portion, the first bridging portion carrying or otherwise including a first electrode or transducer,

wherein the first bridging portion is configured to expand radially outward from the support member in conjunction with the first distal end portion moving proximally toward the first proximal end portion and/or the first proximal end portion moving distally toward the first distal end portion, and

a second radial-expansion member having—

a second distal end portion operably connected to the support member at a third position along the length of the support member, the third position being between the first and second positions,

a second proximal end portion operably connected to the support member at a fourth position along the length of the support member, the fourth position being proximal to the second position, and

a second bridging portion extending between the second distal end portion and the second proximal end portion, the second bridging portion carrying or otherwise including a second electrode or transducer,

wherein the second bridging portion is configured to expand radially outward from the support member in conjunction with the second distal end portion moving proximally toward the second proximal end portion and/or the second proximal end portion moving distally toward the second distal end portion,

wherein the first radial-expansion member and the second radial-expansion member are configured to expand radially outward from the support member independently of each other.

15. The neuromodulation catheter of claim **14** wherein the first and second radial-expansion members are resiliently biased to expand the first and second bridging portions, respectively, radially outward from the support member.

16. The neuromodulation catheter of claim **14** wherein the neuromodulation element has an asymmetrical cross section in all transverse planes intersecting the second bridging portion.

17. The neuromodulation catheter of claim **14** wherein the second radial-expansion member is slidably connected to the support member via the second distal end portion and fixedly connected to the support member via the second proximal end portion.

18. The neuromodulation catheter of claim **14** wherein the second radial-expansion member is slidably connected to the support member via the second proximal end portion and fixedly connected to the support member via the second distal end portion.

19. The neuromodulation catheter of claim **14** wherein the second radial-expansion member is slidably connected to the support member via the second proximal end portion and via the second distal end portion.

20. The neuromodulation catheter of claim **19** wherein the support member includes one or more stops positioned to restrict longitudinal movement of the second proximal end portion and/or the second distal end portion.

21. A neuromodulation method, comprising:

advancing an elongate shaft of a neuromodulation catheter toward a treatment location within a body lumen of a human patient while a neuromodulation element of the catheter is in a low-profile delivery state;

independently expanding a series of bow springs of the neuromodulation element one at a time in a distal-to-proximal sequence as the neuromodulation element transitions from the delivery state to a deployed state at the treatment location;

energizing electrodes and/or transducers carried by the bow springs to modulate one or more nerves of the patient while the neuromodulation element is at the treatment location and in the deployed state.

22. The neuromodulation method of claim **21** wherein:

advancing the shaft includes advancing the shaft while the neuromodulation element is disposed within a sheath; and

independently expanding the bow springs includes retracting the sheath relative to the neuromodulation catheter and/or advancing the neuromodulation catheter relative to the sheath so as to allow the bow springs to resiliently urge the electrodes and/or the transducers toward an inner surface of a wall of the body lumen.

23. The neuromodulation method of claim **21** wherein independently expanding the bow springs includes urging the electrodes and/or the transducers into contact with an

inner surface of a wall of the body lumen at a series of longitudinally and circumferentially spaced-apart contact regions.

24. The neuromodulation method of claim **23** wherein the contact regions are disposed along a helical path.

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